경제학박사학위논문

# Interest Rates, House Prices, and Inequality

## 이자율과 주택가격 및 자본이득 불균형

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# Abstract

## Interest Rates, House Prices, and Inequality

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House prices in Seoul showed rapid growth during the 2010s boom. House price changes during the boom were asymmetric in that the higher-priced houses experienced higher rates of price appreciation. The capital gain consequences from this asymmetric appreciation brought worsened wealth inequality. This paper provides historical evidence on the effects of interest rate changes to asymmetric changes in house prices, with a vector-autoregressive model. An assignment model is built to analyze distributional changes in house prices during the boom. The model shows that lower interest rates, which historically accompany widened interest spreads, can result in asymmetric price appreciation observed in data. Most asymmetry comes from the self-reinforcing indirect effect, which suggests that a long trend of lowered interest rates may have brought a large asymmetry in house price changes.

**Keywords :** House Price, Interest Rate, Inequality, Assignment Model, Vector-autoregressive Model

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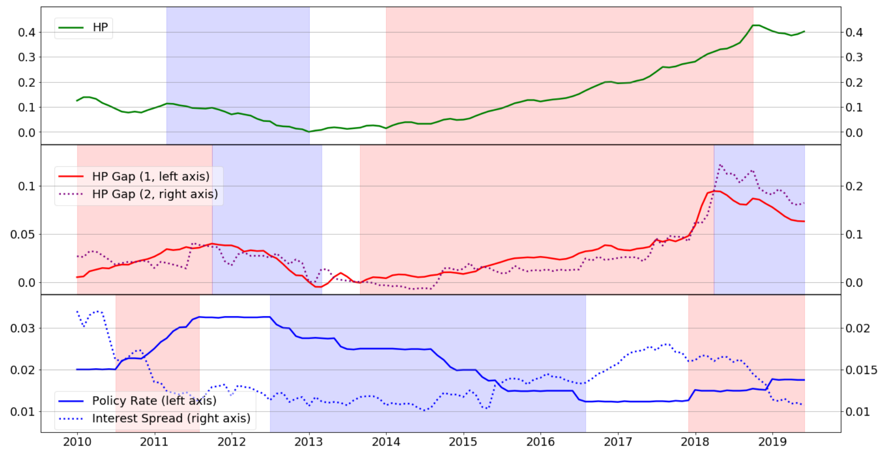
# I. Introduction

After the 2008 global financial crisis, the housing market of Seoul entered a moderate downtrend. As can be seen in [Figure 1], after small fluctuation, the transaction-based house price index of Seoul ("HP") reports a decreasing trend in house prices from early-2011 to end-2012. However, after a stable period in 2013, house prices turned to an uptrend, experienced rapid growth until the peak at the end-2018. During the period, the house price index records over 41% of nominal price appreciation, which corresponds to over 8% annually on average.

Notably, house price appreciation during the boom was not symmetric; increasing rates of expensive houses were higher than those of cheaper houses. The middle graph of [Figure 1] demonstrates the gaps between higher-priced houses and lower-priced houses. The solid line stands for the regional gap, which is the differences in price changing rates between two regions, normalized to zero at the end of 2012[1]. Similarly, the dotted line shows the quality gap, which is the differences in price changing rates between two groups—the 5th house price quintile group and the 1st quintile group in Seoul. Both price gaps show very close patterns. They seem to be positively correlated with the aggregated house price. Moreover, both measures suggest that the house price gap had been widened during the 2010s

[1]The higher-priced region is represented by three districts in Gangnam, which are the most expensive regions in Seoul. As a countparty, the lower-priced region is chosen as three most populated districts in Gangbuk. More specifically, three districts in Gangnam refer to Gangnam-Gu, Seocho-Gu, and Songpa-Gu, while three districts in Gangbuk refer to Nowon-Gu, Eunpyeong-Gu, and Seongbuk-Gu.

Figure 1: Trends for house prices, house price gaps, and interest rates

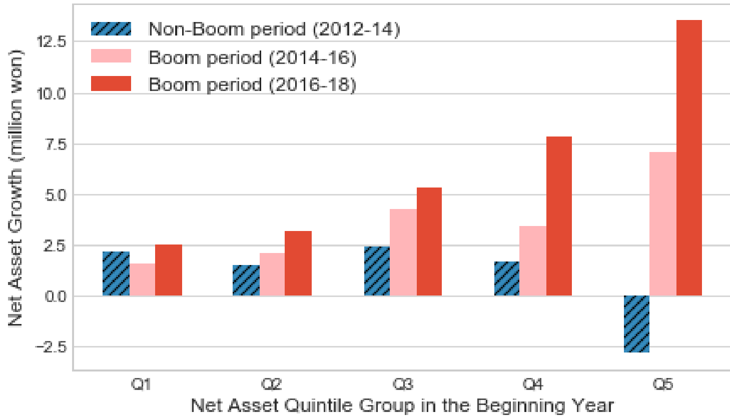



*Note*: Three graphs demonstrate house prices ("HP"), price gaps between houses ("HP Gap"), and interest rates, each from top to bottom panel. The graph for HP depicts the transaction-based house price index of Seoul, as log differences to the end of 2012. Two graphs for HP Gap indicate the differences in price changing rates between two groups, normalized to zero at the end of 2012. The solid line is the regional gap, which is the average gap between Gangnam 3-Gu (higher-priced region) and Gangbuk 3-Gu (lower-priced region). The dotted line is the quality gap between the 5th house price quintile group and the 1st quintile group in Seoul. The average price for each quintile group is announced by KB bank. The bottom panel shows the policy rate of the Bank of Korea and the interest spread between borrowing rates and saving rates, measured as the difference between the rate for new housing asset-backed loans and the rate for new savings. All data are on a monthly basis. Each shaded area stands for a trend. The blue (dark) areas are for a downtrend, while the red (light) areas are for an uptrend. The trends for HP and HP Gap are identified with the rule that: a local maximum or minimum point is (1) being the start-point of a trend if the trend lasts longer than one year, and is (2) being the end-point of a trend if one of the future values before the next local extreme point has over 1%p lower (for an uptrend) or higher (for a downtrend) value than the point. The trends for the policy rate are identified if a series of policy rate decisions continued for more that one year without changing in the opposite direction.

boom.

Is this phenomenon—the asymmetric house price appreciation—worth noticing? One of the expected consequences of the boom is worsened wealth inequality. Wealthy households usually own higher-priced houses and more housing assets. Therefore, house price appreciation, especially with the fea-

Figure 2: Changes in wealth during the boom period




*Note*: The figure depicts the average changes in net assets during the period by initial net asset groups. Each of three bars corresponds to a two-year period of 2012-14, 2014-16, and 2016-18, from left to right. More details can be founded in Appendix.

ture that higher-priced houses appreciated more as in the 2010s boom, can lead to imbalanced capital gains from housing assets that make wealthy households more wealthier. Because houses usually take a large portion in a household's portfolio, imbalanced capital gains from housing assets can bring non-ignorable effects on the household wealth distribution. [Figure 2] confirms that the wealthier groups experienced significantly more net asset growth during the boom period, in contrast to the non-boom period. The differences between groups are huge, even considering their income differences.[2] Thus, asymmetric house price appreciation can be viewed as an issue of wealth inequality, which can make the wealth gap between households to be widened.

The next question is what drives the house price boom in the 2010s?

[2]Details can be founded in Appendix.

One of the most notable changes in the mid-2010s is the changes in interest rates accompanied by monetary easing. During the four years from July 2012 to June 2016, the Bank of Korea lowered the policy rate eight times, a total 2%p from 3.25% to 1.25%, which is the lowest level in history. Each shaded area in [Figure 1] indicates a trend—red (light) areas for an uptrend and blue (dark) areas for a downtrend.[3] It seems that the trends of both house prices and the house price gap follow the trends of interest rates in opposite directions, possibly with the lags up to one and a half years. Four years of decreasing trend of interest rates in the mid-2010s preceded 4-5 years of upside trends of house prices and the house price gap.

Can the changes in interest rates result in highly non-uniform changes in house prices observed in the boom? A notable historical feature on interest rates is non-parallel changes in borrowing rates and saving rates. A borrowing-saving rate spread depicted in [Figure 1] shows that the borrowing rate is relatively rigid than the saving rate; the spread had been widened during the downtrend of interest rates, and vice versa. This non-parallel changes may bring non-uniform consequences on the housing market; because participants on the low-end of the housing market are more likely to rely on borrowing, a rigid change in borrowing rates can make effects on low-end markets relatively small, like the one observed during the boom regarding house prices. However, both the validity and quantitative plausi-

[3] A trend of the policy rate is identified based on the series of policy rate decisions having the same direction for more than one year. Trends of house prices and the house price gap are identified with the rule that a local maximum or minimum point is (1) being the start-point of a trend if the trend lasts longer than one year, and is (2) being the end-point of a trend if one of the future values before the next local extreme point has over 1%p lower (for an uptrend) or higher (for a downtrend) value than the point.

bility can be questioned on this explanation.

The primary purpose of this paper is to highlight the role of interest rates changes for the asymmetric house price appreciation during the 2010s boom period. The features described above are analyzed with both a time-series model and a structural model. A time-series model is used to clarify the relationship among variables visualized in [Figure 1], and then a structural model is used for deeper analysis focusing on the house price changes during the boom.

In the model perspective, a majority of macroeconomic models with housing choices assumes perfect mobility of housing units (i.e., marginal tradability of housing units or marginal transformability between consumption and housing goods), which means that houses, as it is commonly assumed for other goods, can be divided into marginal units and be freely added to or detached from existing houses. These assumptions make the marginal price of houses to be equalized, so different per-unit price changes cannot happen. Consequently, these models cannot help to explain different rates of price changes for different houses, as observed in data. The perfect mobility assumption is far from reality since usually both the house itself and its amenities are strictly immobile because of physical reasons. Adopting immobility (or indivisibility) to the model is a way to deal with cross-sectionally different rates of house price changes.

Recently, Landvoigt, Piazzesi, and Schneider (2015) adopted this feature, built a quantitative model with indivisible houses[4]. To handle the match-

[4]More previously, Ortalo-Magne and Rady (2006) and Rios-Rull and Sanchez-Marcos (2008) used models with non-homogeneous houses consisting of two types of houses.

ing problem between heterogeneous households and heterogeneous houses, they brought an assignment problem into the model. Their assignment model[5] was used to explain the pattern of cross-sectional capital gains in San Diego County during the 2000s boom. In their model, market supply is exogenously given from data, so it has an advantage regarding the errors from the model's supply side. However, it suits less for model experiments since the model lacks the model-driven equilibrium. On the other hand, Määttänen and Terviö (2014) used a static model with a one-sided assignment problem, in which homeowners can be not only a "buyer" but also a "seller" in the owner-occupied market, hence the market supply is endogenously given by homeowners. They studied the relation between the distribution of income and house prices under no-trade equilibria.

A model in this paper follows the basic structure from Landvoigt et al. (2015), but adopt a one-sided assignment problem, so the prices are determined from model-induced equilibrium in which both demand and supply are endogenously given. The model helps to explain the asymmetric price appreciation during the boom with several experiments. The indivisible house is a crucial feature that allows non-uniform price changes among houses. Because of indivisibility, housing stock supply cannot be shifted corresponds to a demand shift. Therefore, prices should be solely changed to neutralize the shifted demand without help of housing stock adjustment, if ignoring the new house supply. Consequently, prices are highly appreciated in those markets to which the demand is shifted.

The rest of the paper is organized as follows. In section II, the rela-

[5] Sattinger (1993) provides a review of assignment models.

tionship between interest rate changes and house prices is investigated with a vector-autoregressive (VAR) model. In section III, the structural assignment model is described as well as the choice of parameters. In section IV, the structural model is used to analyze house price appreciation during the 2010s boom. The conclusion and the appendices are followed.

# II. A Time-series Model

In this section, the relationship between interest rates and house prices is investigated with a VAR model. Several studies have used VAR models to reveal the relationship, for example, Aoki, Proudman, and Vlieghe (2004); Bjørnland and Jacobsen (2010); Elbourne (2008); Giuliodori et al. (2002); Iacoviello (2005); Iacoviello and Minetti (2008); and Sutton et al. (2002). They mainly focused on aggregate levels of house prices as a channel of the monetary policy transmission mechanism, while the model here has interests in the dispersion of house prices as well as its aggregate levels.

## 2.1 Model

The VAR model consists of seven variables. The house price (HP), the house price gap (HP Gap) and the interest spread (SP) are added to the core structure with four variables—industrial production (IP,) consumer price (P,) policy stance (PS,) and interest rate (R.)[6]

The data is monthly and used as follows. The seasonally adjusted industrial production index is for "IP," the consumer price index is for "P," and the policy rate of the Bank of Korea is for "R." The transaction-based house price index of Seoul is used for "HP." "HP Gap" is the regional gap, which represents the differences in price changing rates between the Gangnam 3-

[6] A path through new house supply is ignored. It is thought to be limited in a city like Seoul which has inelastic supply. A VAR model including a supply variable suggests that the path can be ignorable at least in the short-run, similar to results in the UK by Elbourne (2008).

Gu and the Gangbuk 3-Gu, described in [Figure 1]. "SP" is measured as the difference between the rate for new housing asset-backed loans and the rate for new savings. "IP," "P," and "HP" enter in logarithms.[7] The data period is slightly over 12 years from January 2006 to May 2018.

The policy stance "PS" stands for the intensity of the Monetary Policy Committee's consensus to adjust the policy rate, which is extracted from the text of the minutes of the Bank of Korea. The methodology follows from Jung (2018). The policy stance is adopted into the model for the proper identification of interest rate shocks. Jung (2018) argued that the estimated policy stance contains information for the policy decision (e.g., future inflation), hence helps to identify policy rate shocks by mitigating the omitted variable problem.[8]

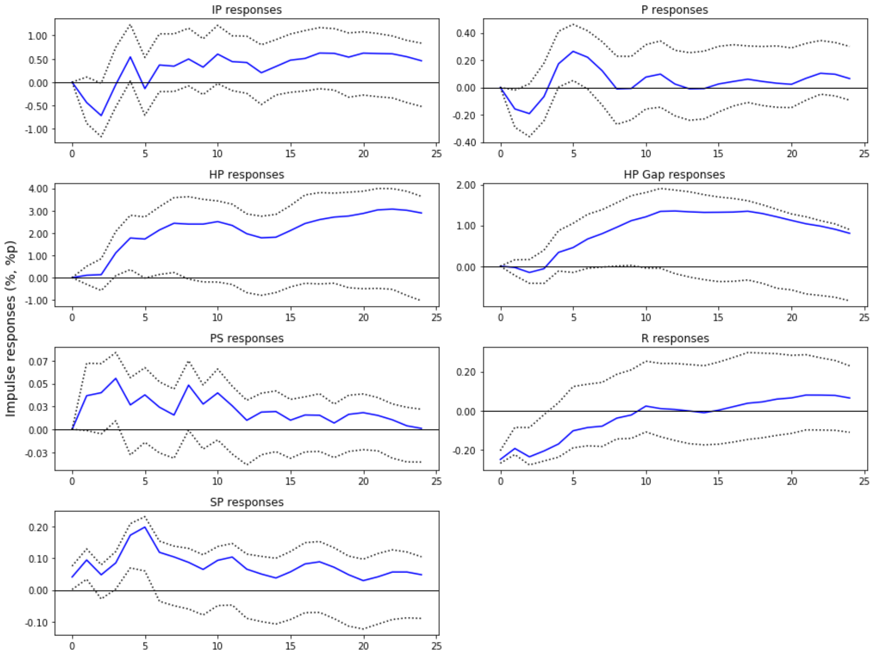
The restriction for identification is recursively given with the order of {IP, P, HP, HP Gap, PS, R, SP}[9]; "IP" is assumed to be the most exogenous. Several information criteria suggest a various number of lags. More than

[7] Results from unit root tests suggest that some variables may have a stochastic trend. However, a VAR model with differenced variables also gives consistent impulse responses to interest rate shocks, so it does not affect the results in this section. A vector error correction model (VECM) can be considered as well (e.g., Iacoviello and Minetti (2008)), but it additionally requires the identification of cointegration between variables that can bring another kind of error in model specification. Note that a VECM with three cointegration rank, as Johansen's trace statistics suggest, is also implemented. It gives similar impulses responses to interest rate shocks if the same short-run recursive restrictions are imposed.

[8] A VAR model often faces a problem called the "price puzzle" that an increase in inflation appears to follow a contractionary monetary policy, contrary to our prior expectation. A persuasive explanation for the puzzle is that if the monetary authority tightens policy in anticipating future inflation, this relationship can be captured misleadingly in model estimation unless the model adopts information on future inflation (see Sims (1992)). If this conjecture is true, the puzzle can be solved by including proper information for the policy decision into the model (Sims and Zha (2006); Christiano, Eichenbaum, and Evans (1994); and Bernanke, Boivin, and Eliasz (2005)).

[9] A sign restriction following Uhlig (2005) is imposed with a slightly larger model that includes the commodity price and the money base as additional variables (and excludes the policy stance.) It also gives consistent responses to interest rate shocks.

Figure 3: Impulse responses to a negative interest rate shock




*Note*: Dashed lines are 90% bootstrapped confidence intervals with 1,000 repetitions. The vertical axis denotes percentage changes for IP, P, and HP Gap responses, and percentage point changes for others.

eight lags would be preferred because the correlation between the policy stance and future inflation shows the peak at lag eight. Consequently, eight lags are chosen for the result.

## 2.2 Impulse Responses

[Figure 3] demonstrates impulse responses to a negative interest rate shock. Dotted lines stand for 90% bootstrapped confidence intervals. "IP" and "P" move in a theoretically expected way to an interest rate shock; no "price puzzle" is observed. The interest spread is widened to the negative interest rate shock, consistent with historical patterns of borrowing rates. Both the house price and the house price gap are shown to be increased. To the negative 25 basis point shock of the interest rate, the house price reaches +3.1% after 23 months, and the house price gap is widened by +1.4%p after 12 months. It is noted that the regional gap used for "HP Gap" is a relatively weak measure; the size of the regional gap is roughly twice smaller than the quality gap shown in [Figure 1].

The VAR model provides historical evidence of opposite responses of house prices and the house price gap to interest rate shocks in aggregate levels. Decreases in interest rates have led to appreciated house prices and more dispersed house price distribution. However, a limited number of variables and a simple model structure limit deeper investigation. In the following sections, a structural model is used for further analysis focusing on house price changes during the boom.

# III. A Structural Model

## 3.1 Model

An assignment model with heterogeneous houses and households is described in this section. Houses differ in their quality indexed with $h$ and distributed continuously within a range of $[0,1]$. The index is ordered that higher indexed houses give higher housing services. It is assumed that all the houses are listed equivalently on the choice set and that can be fully compared under a single measure—the house quality.

Households are represented by their head's characteristics. They differ in their age, income, wealth, and own house. They have finite at most T living periods and confront age-dependent dying probabilities in each period. Once households enter the economy, they choose to keep staying in the economy until their death. Households can own a house as a home and gain utility from housing services $s$ in addition to the consumption $c$. They value bequests with the functional form of $v(w)$, which depends on their wealth at death. With specific assumptions on the utility functions, the optimal utility in period $\tau$ of a household with the age of $a_t$ is expressed as,

$$\max_{\{c_t,h_t,b_t\}} \mathbb{E}_\tau \left[ \sum_{t=\tau}^{\tau+T-a_\tau} \beta^t (1+\mu)^{t\cdot(1-\rho)(1-\gamma)} \left\{ (1-D_t^d) \frac{\left(c_t^{(1-\rho)} s_t(h_t)^\rho\right)^{1-\gamma}}{1-\gamma} + (D_t^d - D_{t-1}^d) \frac{\bar{\nu} w_t^{(1-\rho)(1-\gamma)}}{1-\gamma} \right\} \right] \tag{1}$$

Note that the notation for the individual index is omitted for simplification. Households maximize their expected utility discounted with the rate of $\beta$. At every beginning of periods, households receive a dying shock; $D_t^d$ is an indicator having a value of 1 if the household is in a status of death at the period $t$. Two utility functions share a common parameter $\gamma$, which controls the relative risk aversion. Consumption $c_t$ and housing services $s_t$ are assumed to be combined in a Cobb-Douglas aggregator with a parameter $\rho$. This economy is growing at the rate of $\mu$; every variable except for housing services and the saving rate is defined as a detrended one by dividing by $1+\mu$. Accordingly, house prices would grow at the rate of $\mu$ in a stationary equilibrium path. Households face a budget constraint as follows.

$$c_t + (1+\psi) \cdot p_t(h_t) + T_t^h(p_t) = w_t + 1_{stayer} \cdot \nu \cdot p_t(h_{t-1}) + b_t \tag{2}$$

$$w_t = y_t + (1-\nu) \cdot \hat{p}_t(h_{t-1}) - (1 - \tau^b 1_{b_{t-1} \leq 0})(1 + r_t + \rho_t 1_{b_{t-1} > 0}) b_{t-1}/(1+\mu) \tag{3}$$

$$b_t \leq (1-\delta) \cdot p_t(h_t) \tag{4}$$

Some households who receive a moving shock should move to another house for exogenous reasons. Other households can freely choose either to move or to stay. After seeing the moving shock, households make choices for their consumption, housing services, and borrowing/saving. Moving to another house takes moving costs; the cost is assumed to be proportional to the price of the house with the ratio of $\nu$ and to occur only when selling.

Households should pay for the proportional maintenance cost $\psi$ and the taxes on houses $T_t^h(p_t)$ every period. The tax can be charged non-linearly based on the value of the house.

$b_t$ denotes net borrowing. Households can either save at the rate of $r_t$ or borrow at the rate of $r_t + \rho_t$. The interest spread $\rho_t$ has a positive value and applied uniformly to every household. Interest income from the savings is taxed with the tax rate of $\tau^b$. Households face a borrowing constraint; households can borrow only up a $\delta$ fraction of their housing asset.

The wealth $w_t$ is defined as the mover's net assets plus income after paying the moving costs. Equation (3) says that the wealth is the sum of the income flow ($y_t$), the selling price of the house after paying the moving costs ($(1-\nu)\hat{p}_t$), and the current value of financial asset/liability. With this definition of wealth, the budget constraint equation (2) can be read that households use their wealth to buy consumption goods and a house with corresponding maintenance costs and taxes, and save or borrow the rest. The transaction cost of selling the house is added back to the wealth if a household is a stayer; $1_{stayer}$ is the indicator for the stayers, who do not receive a moving shock and choose not to move.

$$y_t = y^d(a_t) \cdot y_t^p \cdot exp(\xi_t), \quad y_t^p = (y_{t-1}^p)^{\rho_y} \cdot \exp(\varepsilon_t^y) \tag{5}$$

Income $y_t$ is divided into a deterministic part $y^d(a_t)$ and a stochastic part $y_t^p \cdot exp(\xi_t)$. The deterministic part corresponds to age-dependent life-cycle income. $y_t^p$ is persistent with the parameter $\rho_y$. Both $\exp(\xi_t)$ and $\exp(\varepsilon_t^y)$ are assumed to be independent and follow the normal distributions with mean zero. $y_t$ is conceptually after-tax income; after-tax income data is used to approximate the stochastic income process.

Exogenous movers, who receive a moving shock, are facing downward idiosyncratic shock ($\exp(\varepsilon_t^{hp})$) to the house selling price ($\hat{p}_t$); they sell their house at a price $p_t \cdot \exp(\varepsilon_t^{hp})$, possibly lower than its intrinsic price $p_t$. A household who is not an exogenous mover can sell their house at the proper market value $p_t$. The idiosyncratic shock is assumed to follow a one-sided half truncated normal distribution lying on $(-\inf, 0]$ and having a scale parameter $\sigma_{hp}$.

The model economy is for the city and its around area. The main reason for this is to narrow households' spatial choices down; large area such as a country is too big for a single assignment to occur. The population is stationary in that the same number of households enter the economy every period, and they would change their house only within the city area. Hence, the choice set of households are spatially limited in this model. Under this assumption, the equilibrium of the housing market can be defined despite the model's openness as a city economy. All the houses are assumed to be owned by households and there is no supply of new houses, so the housing market is only for existing houses.[10] The cumulative distribution function of existing houses $S_t(h)$ is expected to be unchanged through time.

In the equilibrium, the assignment condition is that every mover should be assigned to one of the market-supplied houses (or equivalently assigned to another mover.) Both demand and supply are given by households; the demand is a set of "to which house" from the movers' housing choice problem, while a set of "from which house" constitutes the supply. This is a one-sided assignment problem in the sense that the assignment occurs within the same

[10] This assumption is thought to be less severe for a fully-developed city like Seoul. The number of new houses is conservatively 2.4% of existing houses in 2017, based on the ratio of total completion to total occupied houses.

group of households. The equilibrium condition can be written as,

$$\int_0^h h_t^{*i,mover_t} di = \int_0^h h_{t-1}^{i,mover_t} di \qquad , for\ every\ h \in [0,1] \tag{6}$$

$h_t^{*i,mover_t}$ is notated for an optimal housing choice of a household $i$ who is a mover at time t. The movers in this equation include newly entered households and the households who die at the period. The equation says that the movers' cumulative demand for house $h$ should be equalized to the cumulative market supply also given by movers. The equilibrium demand and supply would constitute the trade volume of the period.

The equilibrium condition (6) is not so convenient since both demand and supply would change simultaneously from any parameter changes. Another expression using the unchanging distribution of entire houses can be more useful. Because the stayers keep their housing choices unchanged, their demand and supply are equal by definition.

$$\int_0^h h_t^{*i,stayer_t} di = \int_0^h h_{t-1}^{i,stayer_t} di \qquad , for\ every\ h \in [0,1] \tag{7}$$

Note that the supply by movers is always a subset of whole houses, and the supply by stayers becomes its complementary set. Consequently, the sum of supplies by two groups should be equal to the distribution of all existing houses. The alternative equilibrium condition can be provided as follows.

$$\int_0^h h_t^{*i,all} di = S_t(h) \qquad , for\ every\ h \in [0,1] \tag{8}$$

The demand of all the households including the stayers should be equal to the distribution of all existing houses.

A stationary equilibrium in this open economy is given by time-invariant tax rates and prices $\{p_t, r_t, \rho_t\}$, time-invariant decision rules for $\{c_t, h_t, b_t\}$, and the time-invariant distribution of households over the state-space. The decision rules are the optimal choices from equation (1), and the housing market equilibrium condition in equation (8) is satisfied. In the following sections, the stationary equilibrium is used to mirror the economy at the beginning of the boom period.

## 3.2 Parameters

Parameters are basically set based on the Seoul Capital Area in the year of 2014.[11] The year of 2014 corresponds to the beginning of the 2010s boom period. House prices had been in moderate changes until the end of the year, hence the year of 2014 is thought to be relatively safe in assuming an equilibrium with stationary expectations. The distribution of house prices follows the Housing Survey 2014 of which the survey point is at the middle of 2014 (July 7). Other parameters are basically set to be in line with this

[11] The Seoul Capital Area is the metropolitan area that includes Seoul. It is a very densely populated area. About 49% of total households and a slightly higher percentage of population of the country live in the area.

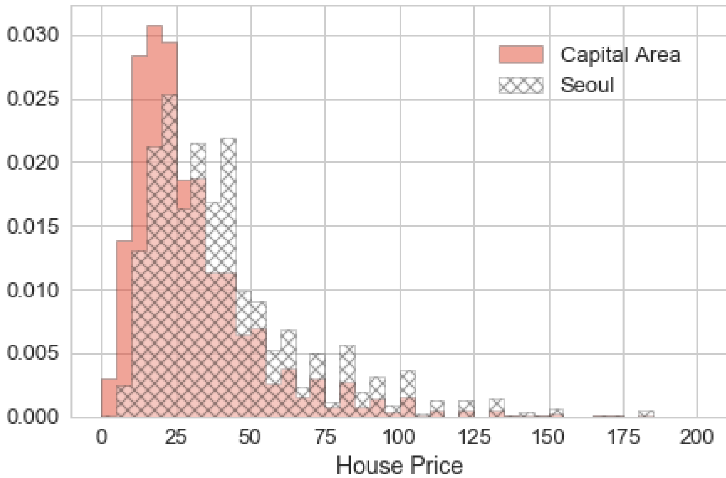
time point.

The Housing Survey reports the home price of 20,000 households (if they own a home) as well as their earnings, income, wealth, housing tenure, and some information on the head's characteristics. The house price is based on its expected market price. The Housing Survey sample is designed to be a sub-sample of the Population and Housing Census 2010, and some households who lived in new apartments built after the Census are added. Total 4,678 households exist as a homeowner who lives in the Seoul Capital Area.

The distribution of house prices is right-skewed, as can be seen in the histogram in [Figure 4]. Overall house prices in Seoul are higher than those in the Seoul Capital Area. As houses in the model are differentiated only in their house quality, the average house prices of Seoul can be obtained just using the weights of houses in Seoul, although the model economy is built for the larger area—the Seoul Capital Area. If assuming that the house prices in the survey can be used as a measure for house quality index, the cumulative distribution function of houses on the quality domain $S_t(p_t)$ can be obtained from data. More specifically, the empirical CDF is used after smoothed with a local regression; the locally weighted scatterplot smoothing (LOWESS) with the smoothing parameter 1/6 is applied to the empirical CDF on the domain of log house price. The smoothed points are further interpolated with monotonic cubic splines.

The unit of a period is three years. Households enter the economy at their age of 30, live at most 20 periods, and surely die at the end of the period of age 90. The growth rate of economy $\mu$ is assumed to be 2.7%,

Figure 4: Histogram for house prices




which corresponds to the mid-term forecast on economic growth by several institutions, including the Bank of Korea. The parameter $\gamma$ in both utilities is set to 2. The Cobb-Douglas parameter that governs the share between consumption and housing services is 0.2, which corresponds to the average fraction of rental payment to total consumption payment for the renters from the Household Income and Expenditure Survey 2018.

The discount factor $\beta$ and the parameter for the bequest utility function $\bar{\nu}$ are jointly set as matching two moments from the model—the median wealth of all households and the median wealth of households older than age 75—to those from the data. The results give 1.013 for $\beta$ and 10.0 for $\bar{\nu}$. The value of $\beta$, combined with increasing values of dying probability, constitutes decreasing discount factors by ages.

The parameter for the moving costs $\nu$ is important in shaping the trade volume. If there are no moving costs, most households would be a mover in response to a small shock unless other frictions exist. On the other hand, with extremely high moving costs, no households would be a mover in most cases. Either case results in extremely inelastic trade volume. The parameter $\nu$ is calibrated to match the trading volume in the stationary equilibrium equal to 23.8% of total houses, which is the ratio of movers in the Housing Survey 2014. The number of movers in the survey counts the households whose living periods in their current home are under three years. The calibrated value of $\nu$ is 3.3%. Also, $\psi$ for the house maintenance costs is assumed to be 1% annually.

For the financial parameters, the saving rate $r_t$ is set at an annual 1.9% that corresponds to the average of 3-year treasury bond yields for one year before mid-2014, from July 2013 to June 2014, after deducting 1% of a long-term annual CPI inflation rate during 2000-2018. The interest spread between borrowing-saving rates $\rho_t$ is set as an annual 1.1% from the average of differences between the rates of new housing asset-backed loans and the rates of new saving deposits, from July 2013 to June 2014. The borrowing constraint $(1-\delta)$ is 60%, which is the maximum Loan-to-Value (LTV) regulation ratio for commercial banks in June 2014. The tax rate $\tau^b$ for interest income is equal to 15.4%, the capital gains tax rate in Korea.

The probabilities of both the moving shock and the dying shock are set as to differ by age. First, the conditional probabilities of moving shocks come from the Housing Survey 2014. In the survey, households report the reasons why they moved to the current house. Among them, only exogenous reasons are identified for the calculation. The fraction of households who became a mover by exogenous reasons constitutes the probability of receiving a moving shock. Meanwhile, the dying shock uses data from the 2015 Population Projections for Korea. The ratio of died people in the Seoul Capital Area by age groups are used for the probabilities.

The stochastic income process has three parameters—(1) $\rho_y$ : the AR1 coefficient parameter for persistent income $y_t^p$, (2) $\sigma_y$ : the standard deviation for persistent income shocks $\varepsilon_t^y$, and (3) $\sigma_\xi$ : the standard deviation for transitory income shocks $\xi_t$. These parameters and the deterministic life-cycle income profiles $y^d(a_t)$ are estimated with household income data from the Korean Labor & Income Panel Study (KLIPS). Appendix summarizes details for the estimation. The resulting numbers are 0.918 for $\rho_y$, 0.181 for $\sigma_y$, and 0.248 for $\sigma_\xi$.

The persistent income process is discretized using the Tauchen method, as a Markov process with nine states evenly spaced within the [-3, +3] standard deviation interval. The income distribution for newly entered households at their age of 30 is assumed to follow a normal distribution with mean zero and standard deviation 0.541; the standard deviation is estimated using the same dataset of KLIPS but only from households whose age is under 33. The wealth distribution for newly entered households follows the empirical distribution from the Housing Survey 2014, only with households under the age of 33.

The shock ($\varepsilon_t^{hp}$) to the selling price of houses, which follows a truncated normal distribution, needs one parameter as a scale parameter. This parameter $\sigma_{hp}$ is estimated using the transaction data of apartments in Seoul. A detailed description can also be found in Appendix. The number is estimated at 0.113.

Table 1: Model parameters

| Parameter | Value | Note |
|---|---|---|
| $\gamma$ | 2 | |
| $\rho$ | 0.2 | The fraction of rental payment to total consumption from the Household Income and Expenditure Survey 2018 |
| $\beta$ | $1.013^3$ | Matching the median wealth of all agents and the median |
| $\bar{\nu}$ | 10.0 | wealth of agents older than age 75 to those from data |
| $\psi$ | 1% annual | |
| $\nu$ | 3.3% | Matching the ratio of movers to the data |
| $\mu$ | 2.7% annual | Mid-term forecast for GDP growth |
| $r_t$ saving rate | 1.9% annual | 3yr Treasury bond yield – Long-term CPI inflation rate |
| $\rho_t$ interest spread | 1.1% annual | Rates for new housing asset-backed loans – Rates for new savings |
| $1-\delta$ | 60% | LTV regulation limit for banks before July 2014 |
| Moving Prob. | by age group | The Housing Survey 2014 |
| Survival Prob. | | The Population Projections for Korea 2015 |

The housing tax policies are quite complex. First, there is a real estate tax. The progressive tax rates are summarized in [Table 2]. The taxable value ranges for different tax rates are set on the nominal values, but here it is assumed that the ranges are expected to increase with the rate of $\mu$, so fixed on the real value. The taxable value for the real estate tax is not the market value of a house; it is stipulated as some fractions of the "standard value" of a house that is determined by the government. Moreover, the fraction is applied differently to the structure portion and the land portion of a house. Simply, a single ratio of the taxable value to the market value is assumed; the taxable value is always 42.9%[12] of its market value for every house.

There are several other taxes on houses. Twenty percent of the real es-

[12]This number corresponds to the ratio of the total taxable value to the total market value in 2014, estimated by Park (2018).

Table 2: The real-estate tax rates by ranges of taxable value

| Taxable Value (million won) | Marginal Tax Rate |
|---|---|
| below 60 | 0.1% |
| 60-150 | 0.15% |
| 150-300 | 0.25% |
| over 300 | 0.4% |

tate tax is added as the name of the local education tax. The local real estate tax is imposed as the amount of 0.14% of the taxable value. In addition, the local facility tax can be charged to houses; it also has progressivity but has a different tax system with more complexity. (e.g., the tax amount can differ by house characteristics such as size, floor, and age.) Here, it is assumed to be 19% of the real estate tax.[13] Moreover, the combined real estate tax, which is charged on the total value of whole houses owned by a single individual, also exist. It is charged only if the sum of taxable value exceeds 900 million won, so it only matters for some extremely expensive houses or for some individual who owns lots of houses. Also, it does not fit in the model because it is charged on an individual, not on a household. For these reasons, this tax is ignored.

Finally, the housing service function $s_t(h)$ is set as to make the equilibrium assignment condition in equation (8) be satisfied in the stationary equilibrium. Because house prices $p_t(h)$ are given with the distribution of houses in the 2014 Housing Survey, the housing service function gives degrees of freedom for equation (8). With the housing service function, corresponding house prices become time-invariant equilibrium prices in the sta-

[13] The total charged amount of the local facility tax is approximately 19% of the real estate tax on houses in the Seoul Capital Area, in 2014.

Table 3: Quantiles of wealth distributions from the model and data

| Quantiles | 10% | 25% | 50% | 75% | 90% |
|---|---|---|---|---|---|
| Data | 17.6 | 25.1 | 37.3 | 56.0 | 84.8 |
| Model | 16.2 | 24.9 | 37.4 | 54.2 | 73.2 |
| (CDF values for corresponding quantiles from data) | (12%) | (25%) | (50%) | (77%) | (94%) |

tionary equilibrium.[14] The housing service function is assumed to be fixed in the model experiment in the next section; new equilibrium house prices are searched while the housing service function is given as estimated here.

## 3.3 Model Fit

The Housing Survey 2014 can be used to evaluate the model fit as it has information on household characteristics as well as house prices. First, [Table 3] compares the wealth distribution from the model with the data. Note that the parameters are set to match the median. The quantiles of the wealth distribution from the model are slightly undervalued than those from the data, but the differences are not huge. Two percent more households are observed in the model below the 10th percentile from the data, while 4% more households are below the 90th percentile from the data.

[Table 4] compares the housing choices under the equilibrium assignment to their counterparts from the data. [Panel A] and [Panel B] summarize quantiles of housing choice distributions each by wealth and income groups. The data tells that the housing choices of households are monotonically in-

[14]The estimated housing service function gives a less right-skewed distribution of houses on the domain of house services, compared to that on the price domain shown in [Figure 4].

creasing with their wealth and income groups. The equilibrium results of the model well describe this feature.

[Panel C] observes the average ratio of housing assets to net assets, by groups divided along the ratios of income to wealth. The net assets equal to the wealth minus income following the definitions of the model. As can be seen in both the model and data, households choose to have a higher-priced house relative to their net assets if their portion of income is higher in their wealth; households whose income flow has a larger portion in their wealth have a tendency to own more housing assets despite its illiquidity. The model also captures this feature close to the data.

Table 4: Housing choices from the model and data

**[Panel A] Quantiles of housing choices by wealth groups**

| Wealth Group | Model | | | | | Data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10% | 25% | 50% | 75% | 90% | 10% | 25% | 50% | 75% | 90% |
| bottom 25% | 4.7 | 8.1 | 10.5 | 13.8 | 17.8 | 6.4 | 9.9 | 12.8 | 16.7 | 20.8 |
| 25-50% | 13.2 | 16.1 | 19.5 | 23.3 | 28.0 | 13.2 | 16.2 | 20.0 | 24.8 | 29.9 |
| 50-75% | 20.7 | 23.8 | 28.9 | 33.9 | 40.1 | 19.5 | 24.2 | 29.7 | 35.5 | 41.5 |
| top 75% | 31.8 | 37.5 | 46.2 | 58.5 | 87.6 | 28.6 | 35.3 | 49.0 | 64.1 | 88.0 |

**[Panel B] Quantiles of housing choices by income groups**

| Income Group | Model | | | | | Data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10% | 25% | 50% | 75% | 90% | 10% | 25% | 50% | 75% | 90% |
| bottom 25% | 7.0 | 12.0 | 19.2 | 27.3 | 37.9 | 6.9 | 11.6 | 18.4 | 29.6 | 41.3 |
| 25-50% | 9.7 | 13.7 | 21.9 | 32.8 | 45.7 | 9.7 | 13.7 | 19.7 | 31.7 | 49.4 |
| 50-75% | 12.3 | 17.2 | 24.4 | 36.5 | 50.4 | 11.8 | 16.8 | 24.0 | 34.8 | 47.3 |
| top 75% | 18.9 | 24.9 | 36.9 | 52.6 | 79.2 | 17.2 | 24.5 | 34.3 | 49.9 | 78.0 |

**[Panel C] Average ratio of housing assets to net assets by the ratio of income to wealth groups**

| | Model | | | | Data | | | |
|---|---|---|---|---|---|---|---|---|
| | Groups by Income-Wealth Ratios | | | | Groups by Income-Wealth Ratios | | | |
| | 1st | 2nd | 3rd | 4th | 1st | 2nd | 3rd | 4th |
| Ratio of Housing Assets to Net Assets | 0.88 | 0.92 | 0.99 | 1.67 | 0.87 | 0.94 | 1.08 | 1.47 |

## 3.4 Interest Rates and the House Price Boom

The model that has been built so far is used for experiments to quantify the effects of interest rates changes to the house price distribution. The model adopts the changes in interest rates during the boom, and the resulted changes in house prices are compared to data.

As a first step, two time points—each represents the beginning and the end of the boom period—are set for the measuring. The house price index says that the period of house price boom corresponds to approximately five years from 2014 to 2018. The beginning-point is set at the end of June 2014, because the baseline parameters for house prices come from the 2014 Housing Survey of which the survey point is at July 7, 2014. The end-point is set at the end of December 2018.

In the following, distributional changes in house prices between two time points are measured from data. Also, changes in interest rates between two time points are identified. Then the changes in interest rates are adopted into model's parameters to see what changes in house prices are induced by the interest rates changes.

### 3.4.1 Measuring House Price Changes from Data

It is already shown in the Introduction that the house price gap is widened during the 2010s boom. However, to compare data with the model, more specific numbers for price changes by each house quality are required. The transaction data in Seoul is used for the estimation of those numbers.

The data of all the transactions of houses are publicly provided by the

Ministry of Land, Infrastructure, and Transport. One-year transaction data is used to represent house prices of each time point; the one year from January 2014 to December 2014 is used for the beginning-point, while the one year from June 2018 to May 2019 is for the end point.

The repeated-sales data is constructed with these two periods of data. The data has information on address (a building address or a complex address for multi-family residentials,) floor, and size of houses. Houses are considered as the same house if they have an identical address, size, and floor (except for underground-floor houses.) In each year, outliers whose price is above or below more than 5% of the median price of the same houses are excluded.[15] The final dataset is built as a collection of transactions of houses that are observed in both periods and that are traded more than two times in each period. With this dataset, the price function—a function from the beginning point prices to the end point prices[16]—is estimated.

The price function is estimated with a spline regression of order 3 with 30 knots. Knots are set to have the same number of observations per knot. Note that the result is insensitive to the number of knots within a considerable range. The estimated price function is used to calculate the average price changing rates between two time points by quality groups. The five quality groups are divided using quintiles from the Housing Survey 2014. Note that the same quintiles are used for the model. In addition, house

[15]Houses are often traded at lower prices if a debt on the house is inherited to the buyer. The deposit on a Jeon-Se rental contract is a typical example of debts that are usually transferred to the buyer, as a part of the house trade contract.

[16]Under the assumption that the house prices in the beginning-point reflect their house qualities, the price function can be thought of as a function from house qualities to the end-point prices, by using the beginning-point prices as a measure for house quality.

Table 5: House price changes during the boom from data

| | Quintile Group | | | | |
|---|---|---|---|---|---|
| | 1Q | 2Q | 3Q | 4Q | 5Q |
| Average rates of price changes (%) | 18.5 | 25.1 | 27.7 | 30.7 | 37.4 |

weights for the group average are also used as identical to the model. Because the same quantiles and weights are used for both the model and data, the average prices by groups are comparable. The estimated average price changing rates by quintile groups are shown in [Table 5]. Note that both the trend growth rate measured by the GDP growth rate and the CPI inflation rate are deducted from nominal rates. The rates of price increases are monotonic by groups; the 1st quintile group experienced the lowest 18.5% price increases, while the 5th quintile group had the highest, 37.4% of increases during the boom.

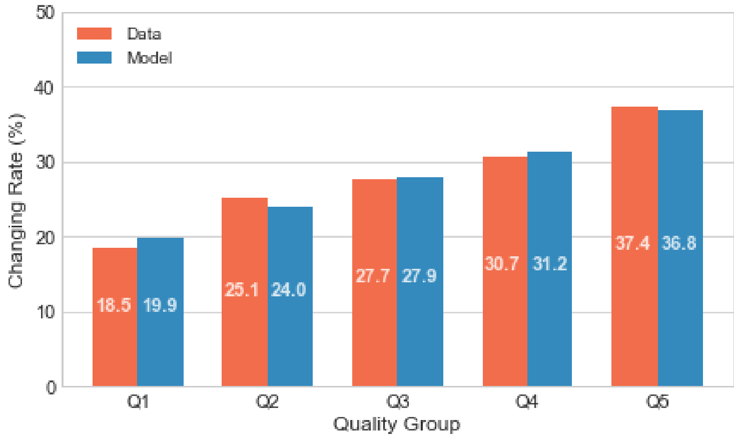
### 3.4.2 House Price Changes from the Model

As a next step, the model-induced distributional changes in house prices are measured while adopting the changes in interest rates into the model. First, parameters for interest rates at the beginning and the end point are identified. The interest rates at the beginning point uses the baseline parameters. The interest rates at the end-point are measured as one-year averages in 2018 in an identical way to the baseline parameters. Comparing two points, saving rates were lowered by 0.8%p from 1.9% to 1.1%, while the spread increased by 0.4%p from 1.1% to 1.5%, which means that borrowing rates were lowered by 0.4%p, less than the saving rates. These numbers are consistent to the historical patterns of rigid borrowing rates.

The new equilibrium prices are investigated under the situation that the distribution of households is at the stationary equilibrium but that the interest rates are now changed to end-point parameters. For future expectations, simple assumptions are made. The interest rates are expected to be kept at the lowered levels for two periods (six years) and then revert back to beginning-point parameters. This expectation may not be overstated since, in data, long-term interest rates had fallen more than short-term rates during the boom period. (e.g., yields for the 10-year Treasury bond had lowered 0.2%p more than the 3-year Treasury bond.) Static expectation is assumed for future house prices; households believe that the real house prices would be at their new equilibrium level except for the trend growth.[17] Note that the assumption of static expectation affects neither the definition nor the result

[17]This static expectation implies neutral expectation on not only aggregated levels but also the distributions of future house prices. Because two time points are chosen to be close to a local minimum or maximum point of prices, the static expectation may not be problematic choices for these points, at least in aggregated levels.
If the full information rational expectation (FIRE) is considered, it is natural to find a transition path in which increased prices from lowered interest rates return to the stationary equilibrium levels. Therefore, households would expect house prices to be lowered in the future along the transition path. However, the negative price expectation at the end point is questioned. The Consumer Survey Index for one-year future house prices in Seoul reported a value of 95 at the end of 2018, which corresponds to only a slightly negative price expectation, and it was only temporary; it quickly reverted to a positive expectation within six months. In a general manner, the evidence for FIRE on the house price seems to be weak, even for the aggregated level of prices.
It is worth noting that the asymmetric pattern of price appreciation is also preserved under FIRE. However, the size of appreciation appears to be smaller because of negative expectations. The size becomes larger as the expected length of lowered interest rates becomes longer. If households expect permanent changes in interest rates, the model under the FIRE can explain 60-70% of price changes observed in data, while the important pattern—monotonically increasing appreciation rates—is preserved.

Figure 5: House price changes during the boom from the model and data




of the stationary equilibrium. Therefore, both equilibrium at the beginning-point and the end-point can be interpreted as a result under the static expectation on future house prices.

[Figure 5] describes the rates of price changes from the model with their counterparts from data. Similar to the patterns from data, house prices from the model show monotonic rates of increase by house quality groups. The changing rate in the highest quality group was 36.8%, while the rate in the lowest group was 19.9%. The result shows that the changes in interest rates with simple assumptions on expectations can result in similar patterns of asymmetric price changes during the boom.

### 3.4.3 Why Prices of Expensive Houses Had Increased More?

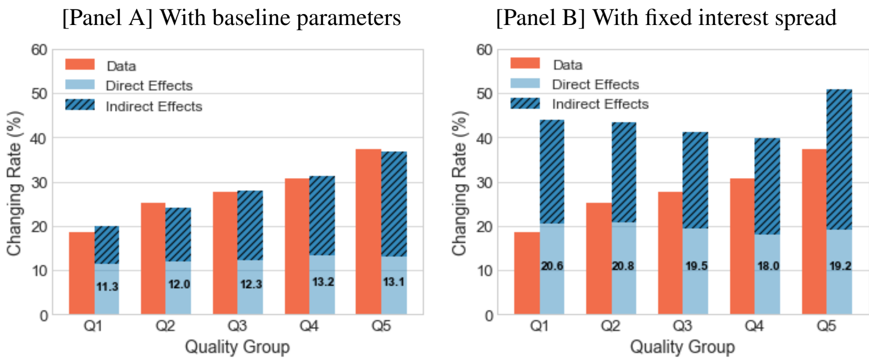
In the model economy, a decrease in interest rates directly stimulates demand for houses through two substitutions. First, houses relatively become more attractive as an investment asset as expected return on financial assets decreases. Second, houses become cheaper as a consumption good as user costs for housing services decrease. Therefore, house demand increases as households rebalance their portfolio by switching financial assets to housing assets and consume more housing services at cheaper prices.

Importantly, an interest rate that a household faces can differ as to whether the household is being a lender or a borrower. In the model, a lender faces the saving rate, but a borrower faces the borrowing rate. Therefore, changes in the borrowing rate and the saving rate give different effects to borrowers and lenders. This leads to non-uniform distributional consequences from interest rates changes; changes in borrowing rates relatively affect more on low-end markets in which borrowers more densely and heavily participate.

A notable feature of interest rate changes during the boom was the non-parallel drops of borrowing rates and saving rates. Borrowing rates had fallen by only half of the drop in saving rates during the period. Smaller drops in borrowing rates relatively limit the demand of borrowers, so the demand in low-end markets. A special feature of the model is the fixed distribution of supply due to the house indivisibility, which implies that an excess demand in every sub-market should be fully neutralized by price changes to match the demand again with the fixed supply in the equilibrium. A higher demand in a submarket requires higher prices in that submarket to press down the demand back to the original level. Therefore, limited expansion of demand in low-end markets can result in limited price appreciation in those markets.

To clarify this, Panel B in [Figure 6] demonstrates the result from the

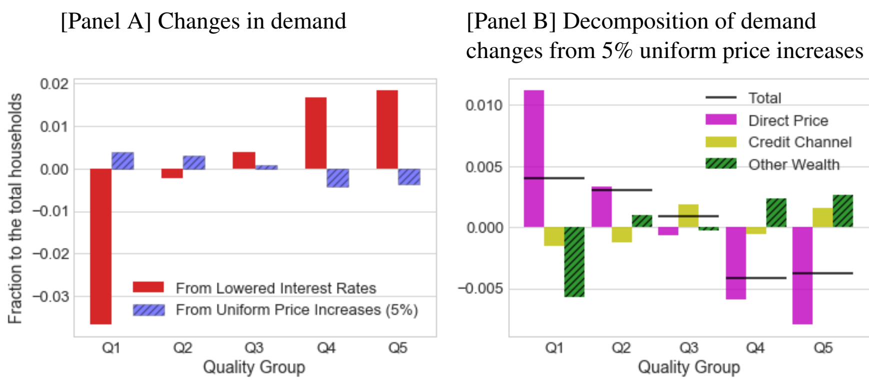
Figure 6: House price changes by different scenarios for interest spreads




case that the interest spread is fixed, not increased by 0.4%p, so the borrowing rate drops more in parallel with the saving rate. As the lowered borrowing rate stimulates more the demand in low-end markets, it can be observed that prices in low-end markets increased more than the baseline. The gap between the highest group and the lowest group becomes smaller than the baseline, and the changes by sub-markets are no longer monotonic. This result suggests that the smaller changes in borrowing rates could be a reason for asymmetric price appreciation during the boom, by limiting relative demand for low-quality houses.

As a next step, changes in demand are decomposed into the direct effect and indirect effect. The direct effect, which comes from the substitution effects described above, raise prices by increasing demand, but it is not the only path for price changes. Increased house prices give capital gains to homeowners, which bring the wealth effect again to demand. The wealth effect works by mitigating two constraints a household faces: the budget constraint and the borrowing constraint. Households choose more housing

Figure 7: Decomposition of demand changes




*Note*: The left bar in Panel A shows the excess demand induced by decreases in interest rates. The right bar shows the demand changes from 5% uniform price increases as a mid-step to the equilibrium. Panel B decomposes the demand changes from this 5% uniform price increases. The black line corresponds to the total effect the same as the right bar in Panel A. Three bars are the decomposition of total effect into the direct price effect and two wealth effects.

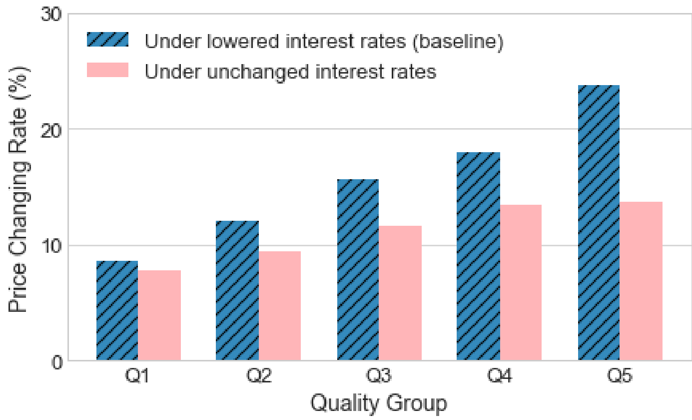
assets with the mitigated budget constraint and can borrow more under the mitigated borrowing constraint if necessary. Both channels further encourage demand, produce positive feedback to house prices.

Panel A in [Figure 6] shows the decomposition of baseline price changes into the direct effect and the indirect effect. The direct effect is captured by eliminating the capital gain channel. (i.e., $w_t$ is fixed.) What is shown in the figure is the transformation of demand changes into price changes. It demonstrates which prices can fully neutralize excess demand induced from the direct effect. The indirect effect is measured as a residual. Two features are worth noticing from the result. First, the size of the direct effect is not impressive; it is hugely amplified by the indirect effect. Second, only small asymmetry is observed from the direct effect; most asymmetry comes from the indirect effect.

To clarify the path of the indirect effect, [Figure 7] demonstrates the demand changes in a step-by-step manner. The left bar in Panel A depicts excess demand by submarkets induced by the changes in interest rates. The right bar shows demand changes from price responses of 5% uniform increases as a mid-step. As can be seen in the left bar, the decrease in interest rates shifts demand to higher quality markets, so excess supply appears in low-end markets while excess demand is observed in high-end markets. Equilibrium house prices should be increased to revert the shifted demand back to low-end markets. In here, 5% uniform price increases work in this way by re-shifting demand from high-end to low-end, although they are clearly not enough to fully neutralize shifted demand. Notably, the changes are not monotonic; demand in the 4th quality market appears to be reduced more than the highest quality market.

To dig this up, in Panel B, the demand changes from 5% uniform price increases are decomposed into the direct price effect and the two channels of wealth effects mentioned above. The price effect catches the demand changes from the increased prices, while the wealth channels are turned off. One of the wealth effects named the credit channel shows the effect of mitigated borrowing constraints. The 5% price increases effectively correspond to 3%p lowered borrowing constraint under 60% of LTV regulation. The credit channel in the figure captures this effect. The other wealth effect is measured as residuals, which include the effect of mitigated budget constraints and joint effects. The figure says that the wealth effects work in the opposite direction to the price effect; they shift demand again from low-quality to high-quality markets. These wealth effects are self-reinforcing,

Figure 8: Indirect effects with and without interest rate changes




push more demands to high-end markets as prices increase. Sufficiently high prices are needed in high-end markets because the equilibrium condition requires shifted excess demand completely back to be neutralized in every submarket. More price increases in high-end markets induce more capital gains in those markets, which lead to stronger wealth effects in high-end markets. Consequently, the wealth effect repeatedly amplifies asymmetric consequences of house prices.

Moreover, the asymmetric wealth effects are further strengthened, combined with a lower level of interest rates. [Figure 8] compares the baseline indirect effect with the indirect effect under the unchanged levels of interest rates. The result shows that the asymmetry becomes more severe with lowered interest rates. This is because, under the lower level of interest rates, households want to use their increased wealth in investing more in housing assets and in consuming more housing services, and want to borrow more the cheaper credit with mitigated borrowing constraints. In other words, the joint effect of the direct substitution effect and the wealth effects also works in a way that strengthens the wealth effects, which brings larger asymmetry of house prices.

# IV. Concluding Remark

This paper tries to highlight the role of interest rates changes to asymmetric appreciation of house prices in Seoul during the 2010s boom. An empirical evidence is provided with a VAR model on the effects of interest rate changes to the cross-sectional house price dispersion. An assignment model with indivisible houses is built for structural analysis on the distributional changes in house prices during the boom. The model shows that the decrease in interest rates with widened interest spreads can result in similar patterns of asymmetric price appreciation observed in data.

The model also shows that large asymmetry in price appreciation mainly comes from indirect channels that arise with capital gains. In the real economy, unlike in the model experiment, the indirect effect happens gradually along the time domain; house prices, as well as corresponding capital gains, had increased gradually during the boom. Hence, the results should be interpreted as the consequences from non-temporary changes. The results suggest that a considerable period of lowered interest rates, especially with sticky borrowing rates, can lead to substantially unequal capital gains from housing assets. The unequal capital gains have strong implication on the household wealth distribution since housing assets are the main portion of wealth to most households. Therefore, a long trend of lowered interest rates should worry about worsened wealth inequality as a side effect.

The monetary authority has less concern about distributional consequences from interest rate changes. If distributional effects from a long trend of monetary easing are non-ignorable, as the results here suggest, its welfare consequences and life-cycle distortion may need to be concerned.

What is neglected in this paper is other changes in economic states and housing market policies. Some of them may be important and have interesting joint effects with interest rates changes, but they are left as future work. The model also lacks owning-renting choices. A critical difficulty in adopting renting choices into the model is that in data, both owning and renting choices seem to be chosen by similar households; typical information on financial status and household characteristics may not be enough to explain owning-renting choices. A renting is thought to be important, especially for low-end markets and for housing choices of the young and the poor, but a number of rich renters can also be observed in data. Therefore, investigating the distribution of owing-renting choices would help us better understand the nature of housing choices and more housing market features.

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## A.1 Changes in Household Wealth during the Boom

The panel data of the Survey of Households Financial and Living Condition is used to describe the changes in household wealth during the boom depicted in [Figure 2]. The survey reports 20,000 households' financial status, such as assets, liabilities, and income. A common sample is used for each period to track down the wealth changes; for example, only households who exist in both 2014 and 2016 surveys are used for the 2014-2016 period. Each of two common samples from 2014-2016 and 2016-2018 surveys is used to describe the boom period, while a common sample from 2012-2014 surveys describes a non-boom period.[18] The survey sample was renewed in 2012, and the sample had been tracked without replacement from 2012 to 2014. After 2014, the panel sample is divided into five sub-samples, and each sub-sample is replaced with a new sample every year. Therefore, the 2014 survey and the 2016 survey as well as the 2016 and 2018 surveys share three common sub-samples. Each sub-sample is designed to have homogeneous characteristics, so the worries on the representativeness of the sample are thought to be small.

Each common sample is further screened to households who lived in Seoul Capital Area. Households whose number of members had changed between two surveys are excluded to reduce capturing the wealth split from household separation. A total of 4,912 households in 2012-2014 surveys are left after the screening, while 2,808 and 2,673 households are left in 2014-

[18]The time point of the survey is at the end of March, so the 2018 survey does not represent the peak of the boom. As four years of survey do not cover the whole boom period, the changes in wealth described here may be undervalued.

Table A1: The net asset growth by initial net asset groups

| | Net Asset Group | | | | | |
|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 5th/1st |
| **Boom period** | | | | | | |
| (a) Net Asset Growth 2014-2016 | 16 | 21 | 43 | 34 | 71 | 4.4 |
| (Ratio to annual disposable income, %) | (86) | (78) | (123) | (76) | (114) | |
| (b) Net Asset Growth 2016-2018 | 25 | 31 | 54 | 78 | 136 | 5.4 |
| (Ratio to annual disposable income, %) | (120) | (112) | (150) | (162) | (212) | |
| **Non-boom period** | | | | | | |
| (c) Net Asset Growth 2012-2014 | 22 | 15 | 24 | 17 | -28 | -1.3 |
| (Ratio to annual disposable income, %) | (126) | (61) | (71) | (41) | (-47) | |

*Note*: The unit for net asset growth is a million won. Each number denotes the average value for the group. Five net asset price groups are divided using the common net asset quantiles from 2014 sample.

2016 and 2016-2018 surveys.

Households are divided into five quintile groups according to their net assets in the beginning year. The same quintiles from the 2014 survey sample are commonly used for every sample. The average net asset growth of households in each group is reported in [Table A1]. The amounts of net asset growth are monotonically higher for the higher initial net asset groups during the boom period. This feature cannot be observed in the non-boom period. The highest group even showed negative net asset growth during 2012-2014. Note that the average house price in the Seoul Capital Area had decreased 3% from March 2012 to March 2014, according to the transaction-based house price index. This house price depreciation mainly brought a negative net asset growth of households in the 5th group during 2012-2014.

The differences in net asset growth between groups appear to be huge in the boom period. The highest group, on average, experienced 136 million won of net asset growth in two years after 2016, which is 111 million won higher than the lowest group. This amount corresponds to over 200% of their annual disposable income in 2014, even though their income is three times higher than the lowest group. The table shows that there was a significant amount of changes in household wealth in a way that wealthy households became more wealthier, which cannot be explained by income accumulation.

## A.2 Approximation of Income Process

The Korean Labor & Income Panel Study (KLIPS) dataset is used for the approximation of the income process.The data is yearly, and the period is after the financial crisis, from 2010 to 2016. The targeted income is the total household income, which includes earnings, transfer income, social security income, and the other income, but except for capital income comes from financial assets and real-estate assets. Households are restricted to male-head homeowners, and households whose total annual income (including capital income) is under 10 million won are excluded.

Equation (5) can be rewritten as follows after taking logarithms.

$$\log y_t = \log y^d(a_t) + \log y_t^p + \xi_t, \quad \xi_t \sim N(0, \sigma_\xi^2) \tag{5.1}$$

$$\log y_t^p = \rho_y \log y_{t-1}^p + \varepsilon_t^y, \quad \varepsilon_t^y \sim N(0, \sigma_y^2) \tag{5.2}$$

Prior to the estimation of stochastic parameters, a deterministic part of income is captured with the following regression.

$$\log y_t^i = \beta_0 + \beta_1 f(age_t^i) + \beta_2 D_{edu}^i + \beta_3 D_{year,t} + \varepsilon_t^i \tag{A.1}$$

$f(age_t^i)$ is the order three polynomials for the head's age, $D_{edu}^i$ is a dummy for the head's education level separated into eight groups, and $D_{year,t}$ is a time dummy. Forecasted income conditional on ages ($\mathbb{E}\left[\log y_t^i | age\right]$) from this equation are used as model parameters for deterministic life-cycle income ($\log y^d(a_t)$). As a next step, a stochastic part of income ($\equiv \hat{x}_t^i$) is obtained by deducting the fitted value $\hat{\log} y_t^i$ from $\log y_t^i$. The stochastic parameters $\rho_y$, $\sigma_\xi$, and $\sigma_y$ are jointly estimated with GMM. The unconditional moment conditions by Floden and Lindé (2001) are used for the identification.

$$\mathbb{E}\left[(\hat{x_t^i})^2\right] - \frac{\sigma_y^2}{1-\rho_y^2} - \sigma_\xi^2 = 0 \tag{A.2}$$

$$\mathbb{E}\left[\hat{x_t^i}\hat{x_{t-s}^i}\right] - \rho_y^s \frac{\sigma_y^2}{1-\rho_y^2} = 0 \tag{A.3}$$

A total of 28 moment conditions are used for the estimation. Parameter estimates are obtained iteratively. Hansen's J statistic for the test of overidentifying restrictions reports the p-value as 0.087, which is not highly satisfactory but could be acceptable considering the simple structure for the income process.

Table A2: GMM estimation results for income process

| Parameter | Estimate | Std. Error | 95% confidence inteval | |
|---|---|---|---|---|
| $\sigma_\xi$ | 0.181 | 0.006 | 0.169 | 0.192 |
| $\rho_y$ | 0.918 | 0.006 | 0.907 | 0.928 |
| $\sigma_y$ | 0.248 | 0.005 | 0.238 | 0.258 |
| | $\chi^2$ | P-value | | |
| Hansen's J statistics | 35.1 | 0.087 | | |

## A.3 Estimation of a Parameter for the House Price Shock

There is one parameter for the house price shock, which is a scale parameter of a one-sided truncated normal distribution from $N(0,\sigma^2_{hp})$ on the support $(-\inf, 0]$. The transaction data of apartments in Seoul during the year of 2014 is used for the estimation. First, transactions of the same apartment are collected. Houses having the same size and located in the same apartment complex are treated as the same houses, and only houses with more than two observations are left in the data. Accordingly, the data has slightly more than 80 thousand observations. The year of 2014 is in a moderate upside trend, so the log prices are detrended with a regression with monthly time dummies. To identify the size of shock, it is assumed that the maximum sales price of a house reflects the intrinsic price of that house quality and that the other prices were observed as a lowered price due to the price shock. With this assumption, realizations of shocks can be inferred.

The estimator of the scale parameter comes from the following relationship between the mean and the scale parameter.

$$\mathbb{E}[\varepsilon_t^{hp}] = -\sigma_{hp}\frac{\phi(0)}{\Phi(0)} \tag{1}$$

$\phi(\cdot)$ is the probability density function, and $\Phi(\cdot)$ is the cumulative density function of a standard normal distribution. By using the average of realized shocks as a sample analogue for the mean, an estimator for the scale parameter $\hat{\sigma_{hp}}$ can be obtained. The estimate has a value of 0.113.

## A.4 Details on Computation

The state space is approximated with a piecewise linear interpolation on discrete points. Twenty-two grid points between zero and four billion won are used for wealth, while 40 grid points between zero and six billion won are used for house prices. Both grids are non-equally divided as to be widened in the high-valued area. Note that the number of grids is shrunk from more dense grids under the confirmation of not hurting the main results. Persistent income states are discretized into nine states with Tauchen method. A finite horizon dynamic programming problem is solved to obtain the policy function.

The price function and the housing service function are parameterized with monotonic cubic interpolation. Seventeen points are used for the interpolation. To get the equilibrium price function, the equilibrium condition in equation (8) is checked. A demand distribution is obtained by interpolating the empirical distribution, which can be driven from the optimal policy function and the distribution of households. The equality of equilibrium condition is evaluated at 14 points that cover 99% of the distribution from 0.5% to 99.5%. The valid values on parameterized points of the price function are searched until the equilibrium condition is satisfied.

# 초 록

2010년대 후반 서울 주택 가격은 가파른 상승세를 나타내었다. 특히 이 기간 동안의 주택 가격 상승은 고가의 주택 가격이 저가의 주택 가격보다 높은 상승율을 보였다는 점에서 비대칭적이었다. 이러한 비대칭적 가격 상승은 주택자산에서 얻는 자본이득의 불균형적인 격차로 이어져 부의 불평등을 악화시켰다. 이 연구는 먼저 벡터자기회귀 모형을 통해 이자율 변화가 비대칭적인 주택가격 변화에 미치는 영향에 대한 실증적인 결과를 제시하였다. 또한 구조 모형을 통해 이자율 변화가 2010년대 후반 주택 가격 상승에 미친 영향을 분석하였다. 분석 결과 이자율 스프레드의 확대를 동반한 이자율의 하락이 자료에서 관측된 바와 같은 비대칭적인 주택 가격 변화를 유발할 수 있음을 보였다. 나아가 주택 가격에 자기강화적인 영향을 미치는 불균형적인 자본이득이 주택가격 상승폭을 크게 확대시키며, 비대칭적 가격 변화의 대부분은 이러한 간접적인 경로에 따른 것으로 나타났다. 이러한 결과는 장기간에 걸쳐 지속된 저금리 기조가 2010년대 후반의 극심한 비대칭적 주택 가격 상승의 원인일 가능성을 시사한다.

**주요어 :** 주택가격, 이자율, 불평등, 저금리, Assignment Model, 벡터자기회귀모형

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